Enhancing Access to the Radio Spectrum

Achieving Efficient Spectrum Usage in Active and Passive Sensing Through a Market Based Approach

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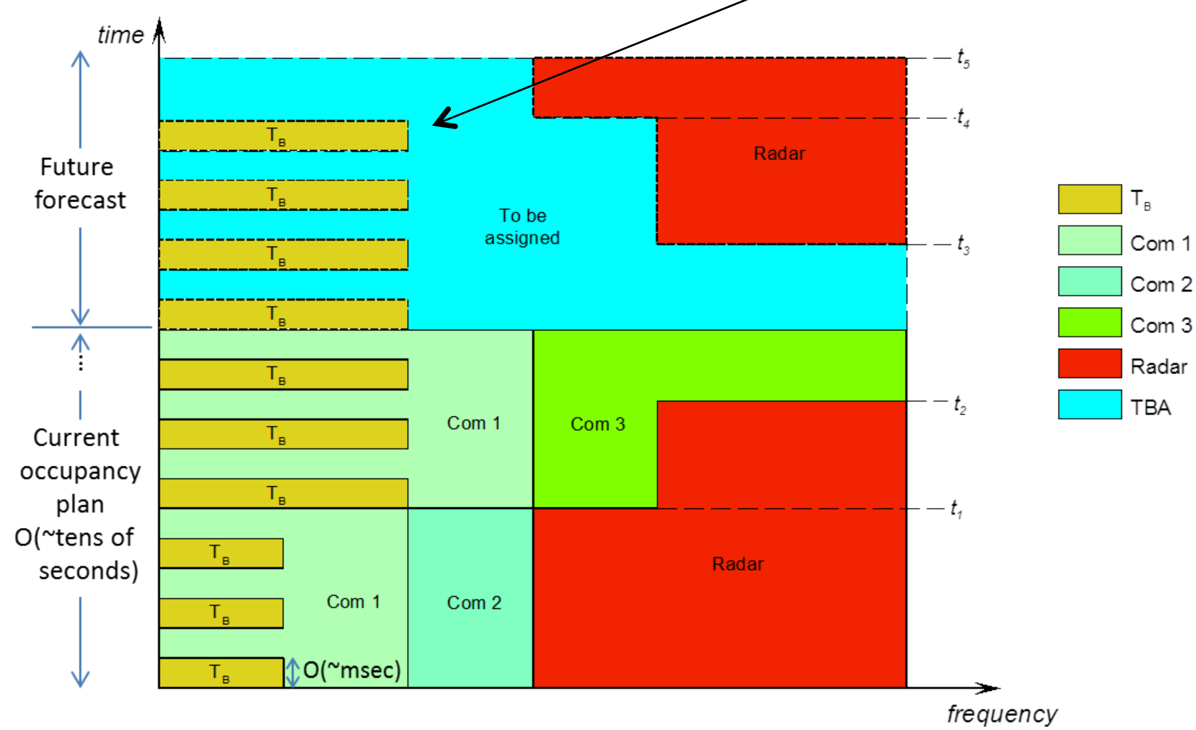
EARS: Achieving Efficient Spectrum Usage in Active and Passive Sensing Through a Market Based Approach

- **Project performing system analyses of microwave radiometry and radar to:**
  - Assess current spectrum usage and potential to share spectrum with other users
  - Examine utility of dynamic spectrum access
  - Predict sensor performance when sharing
  - Determine properties of new spectrum in time and frequency
- **Currently difficult to assess "value" of shared spectrum that is expected to have non-uniform properties in time and frequency**
  - Investigate market designs for this complex scenario
  - Market design must accommodate both commercial and "public good" interests
- **Includes demonstrations to show spectrum sharing among sensing and communication users based on market strategies developed**
  - Both over long (i.e. traditional fixed allocations of free spectrum access) and short (more dynamic allocations) time scales

Dynamic Spectrum Access

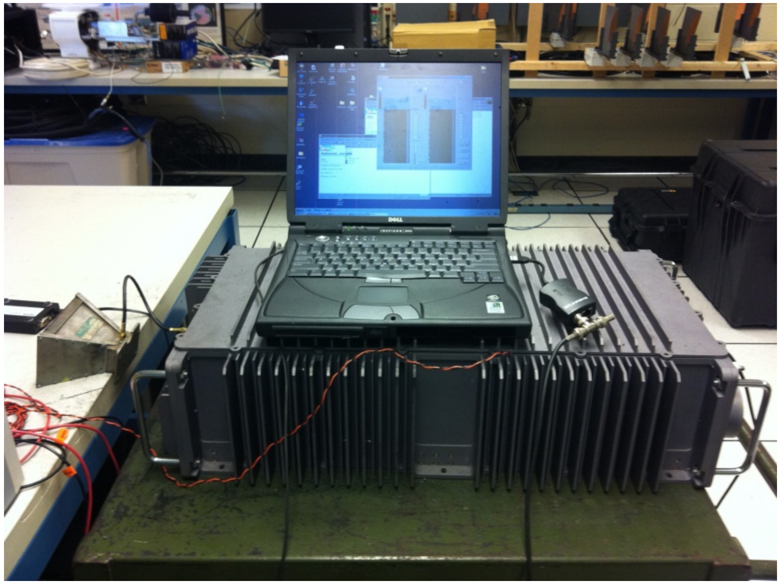
- Dynamic access to spectrum is a key enabling technology for improving spectrum efficiency
  - Being examined extensively for communications system; high US Gov't priority
  - Impact of dynamic spectrum sharing on sensors also warrants investigation
- Microwave radiometry provides critical science information; some blocks of spectrum may be shareable in some situations to achieve greater access to non-traditional spectrum bands
- Rethinking current spectrum access methods can greatly improve rather than compromise future radiometry
- Mechanisms to facilitate dynamic access (i.e. control, assignment, etc.) require development, along with economic issues

Typical radiometer Dicke switching cycle an example opportunity for dynamic access

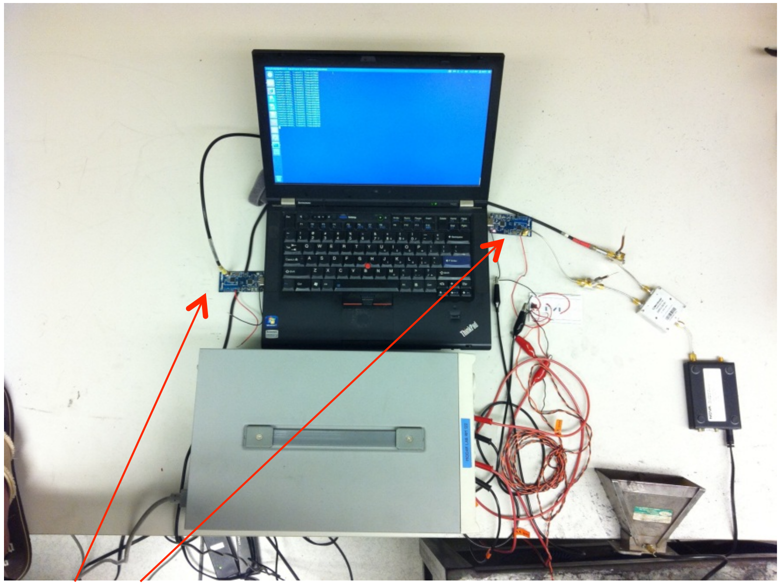


Simple Demonstration of Spectrum Sharing Between Microwave Radiometer and Communication System

- A microwave radiometer observes naturally emitted thermal noise for science measurements; susceptible to interference from communications users
- Typically operate only in spectrum where other transmissions are prohibited
- Dynamic sharing possible because radiometer periodically observes internal cal sources
- A simple demonstration was created to illustrate this idea



MFRAD radiometer of OSU has 37 channels 2-18 GHz; only 3.6 GHz channel used here. Switches from antenna to internal standards every ~270 msec.

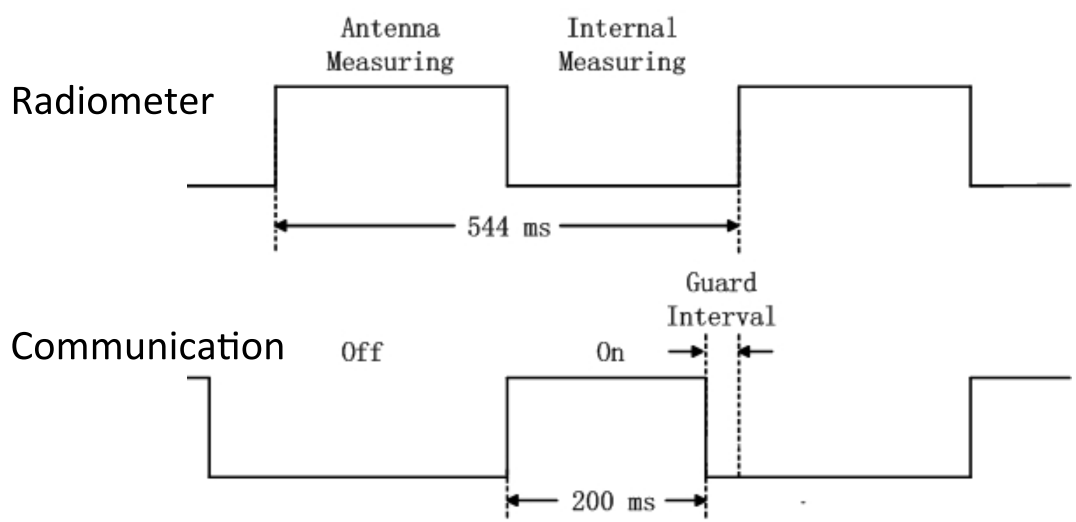


Zigbee mote radios: low data rate (max 250 kbps) but low level control of radio possible. Extra components added to translate default 2.4 GHz to 3.6 GHz

Simple Demonstration of Spectrum Sharing Between Microwave Radiometer and Communication System

- Communication system on when radiometer observes internal loads, turned off when radiometer observes antenna
- Information on radiometer state passed to motes via TTL control line
  - Modify in future to wireless interface or external server information

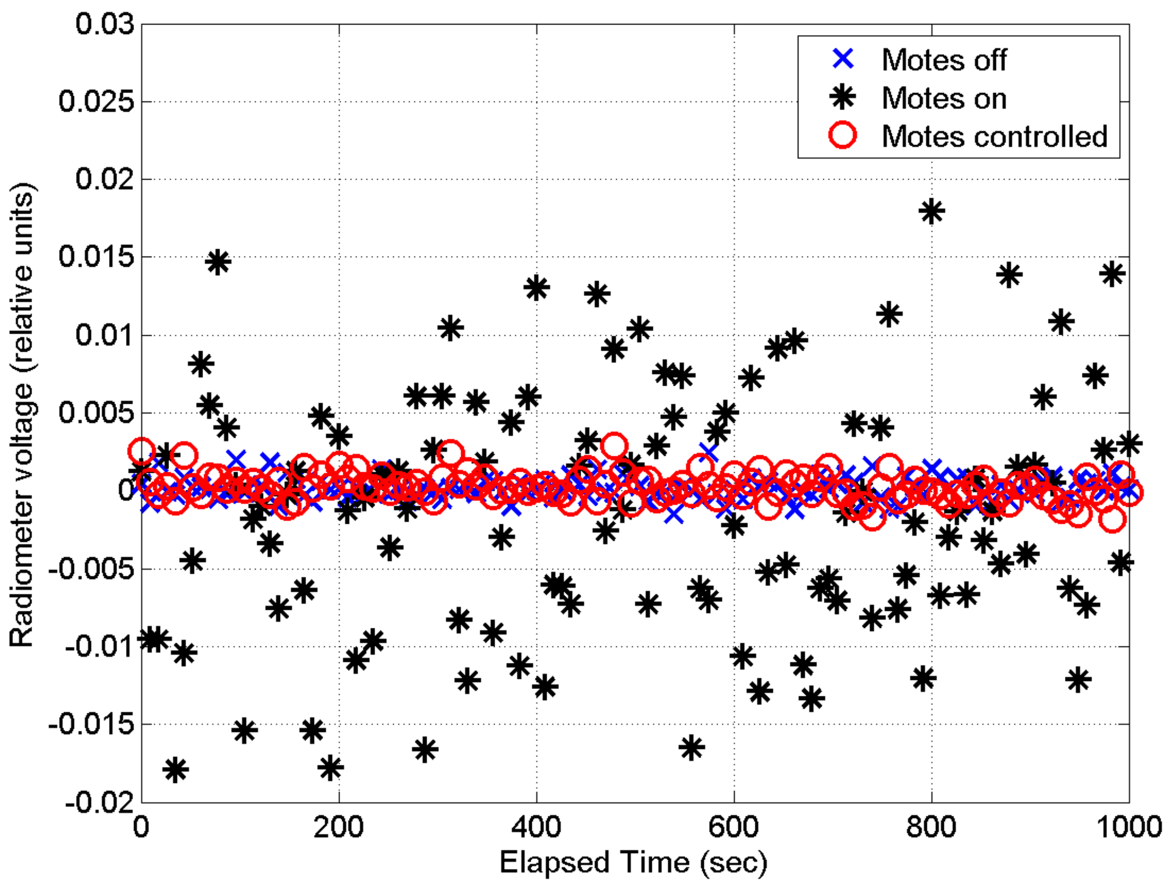
- When radiometer observes antenna, communications transmissions are prohibited
- When radiometer observes internal loads, communications transmissions are allowed
- Transmitter begins to forward packets when signaled by radiometer
- Due to processing delays, transmission duration should be slightly shorter than the radiometer internal measuring period. Therefore a guard interval is set.



Simple Demonstration of Spectrum Sharing Between Microwave Radiometer and Communication System

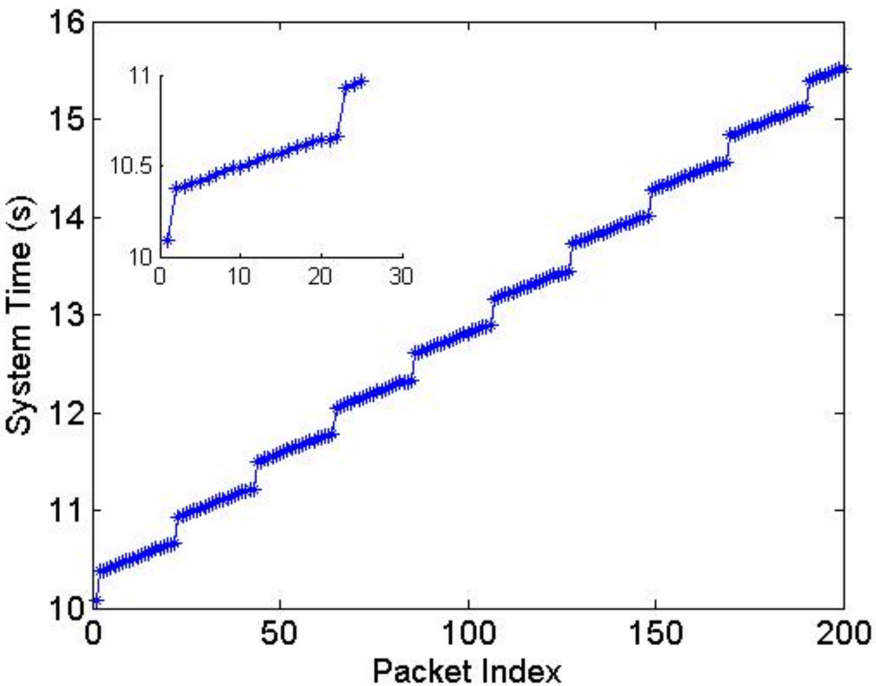
- For the radiometer, need to ensure that communication use does not bias brightness temperature (TB) measurements

- Three cases shown:
  - **Radiometer on, comm system off:** clean TB measurements (blue)
  - **Radiometer on, comm system on:** corrupted TB measurements (black)
  - **Radiometer controls comm system:** spectrum sharing achieved (red)

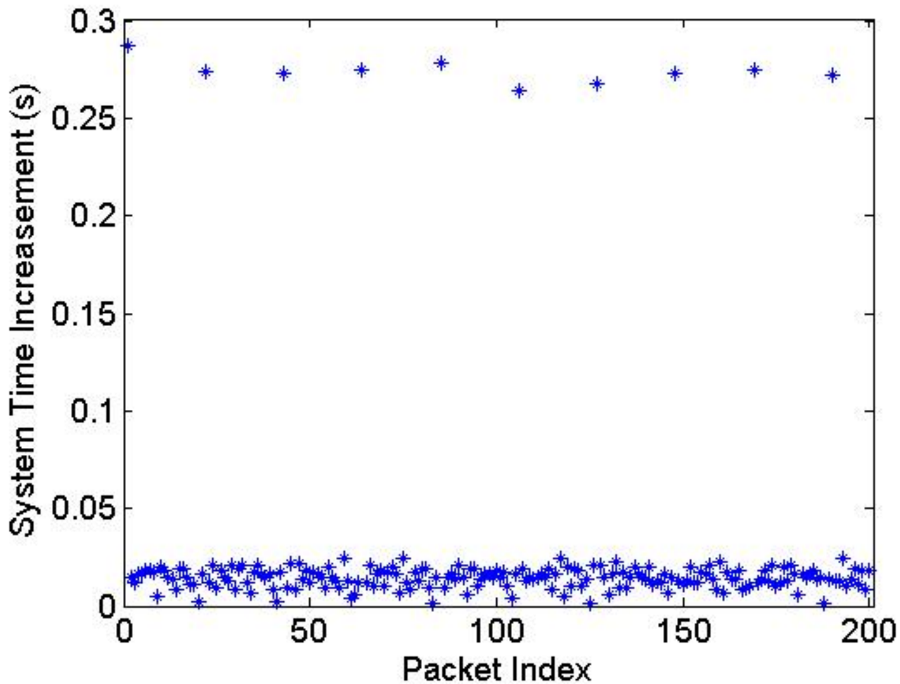


Simple Demonstration of Spectrum Sharing Between Microwave Radiometer and Communication System

- For communications users, data throughput achieved during available time periods is of interest
- A simple message is used for the data: system time at the transmitter
- The data rate achieved is 20 x32 bit packets / 544 ms (≈1 Kbyte per second)



- System time increases linearly in the large scale
- Time gap indicates the antenna measuring period



- Packets are forwarded about every 10 milliseconds
- Antenna measuring period is about 275 milliseconds

Spectrum Sharing for Radar

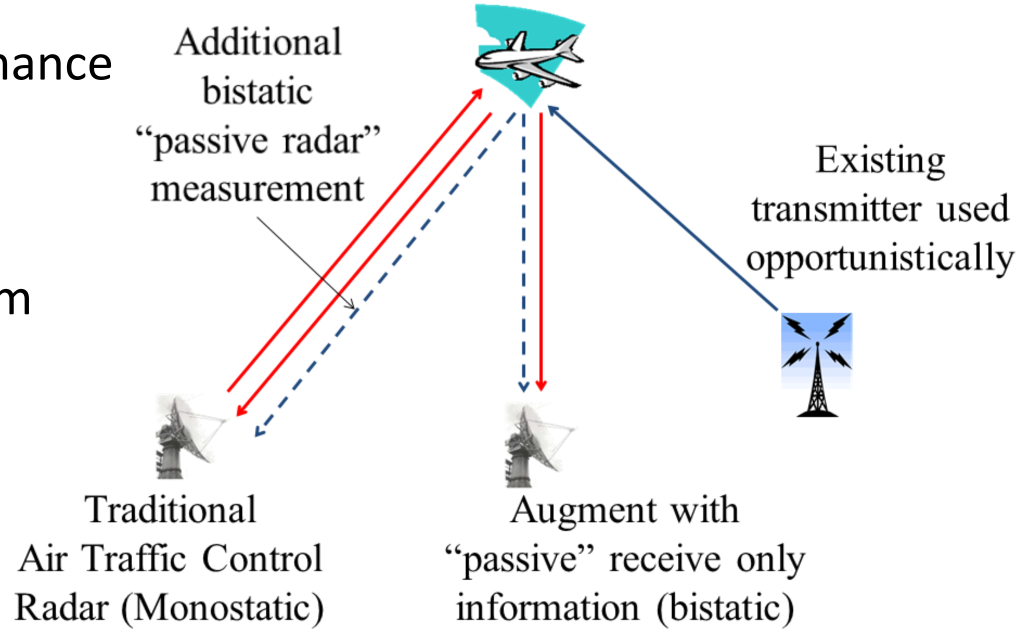
- **Goal: determine methods for spectrum sharing that do not impact performance**
  - Air Traffic Control is adopted as an example application

- One concept for spectrum sharing: augment existing assets with "passive radar"
  - Measure aircraft reflections resulting from existing transmitters
  - Use passive radar only when performance meets regulations
  - May allow "switching off" existing ATC transmitters for some % of time

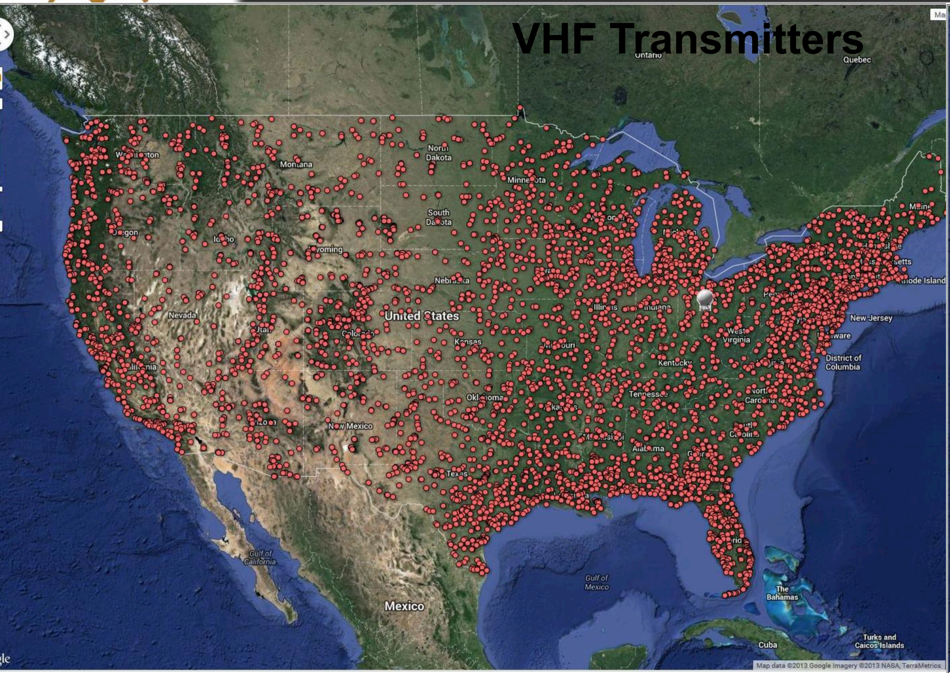
- Must maintain detection performance and location accuracy; also meet existing regulations

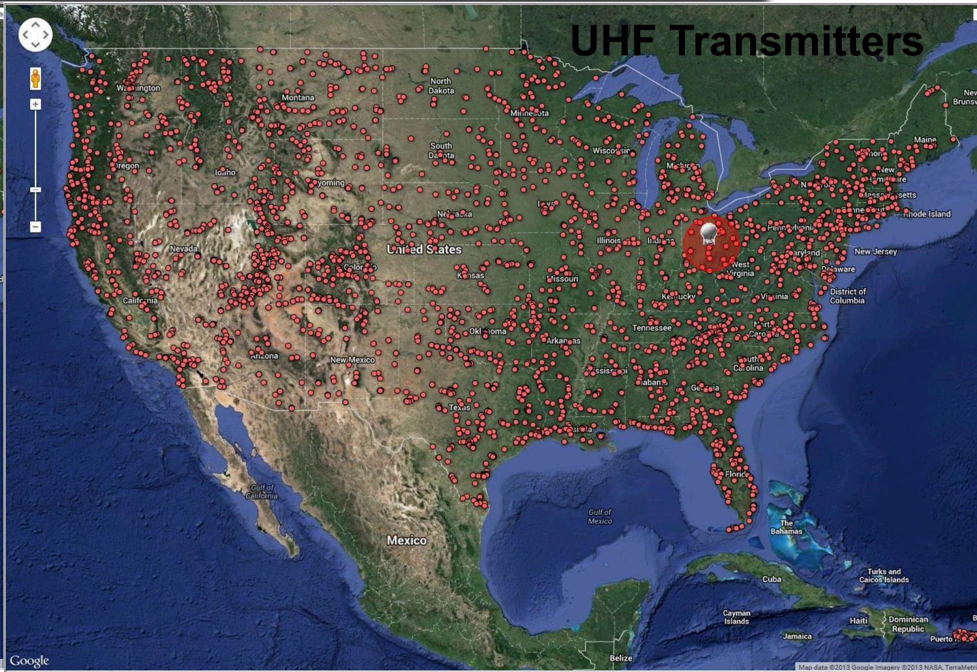
- Project is performing radar system analyses to predict resulting performance

- Also implementing passive radar testbed to allow evaluation of predictions

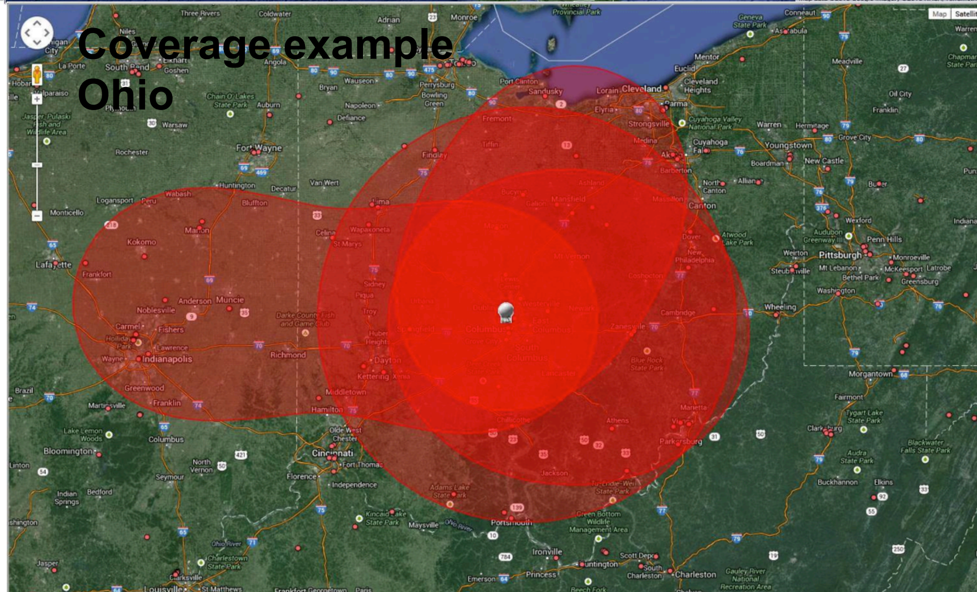


Passive Radar Coverage





- Transmitter density is high and linked to population centers
- A single transmitter of between 100kW and 1MW can cover the area the size of Ohio
- Multiple transmitters (and receivers can be linked to extend and tailor coverage
- Full coverage of the US is possible with as few as 50 to 100 Receivers stations
- Need to understand range and location performance as compared to ATC radar

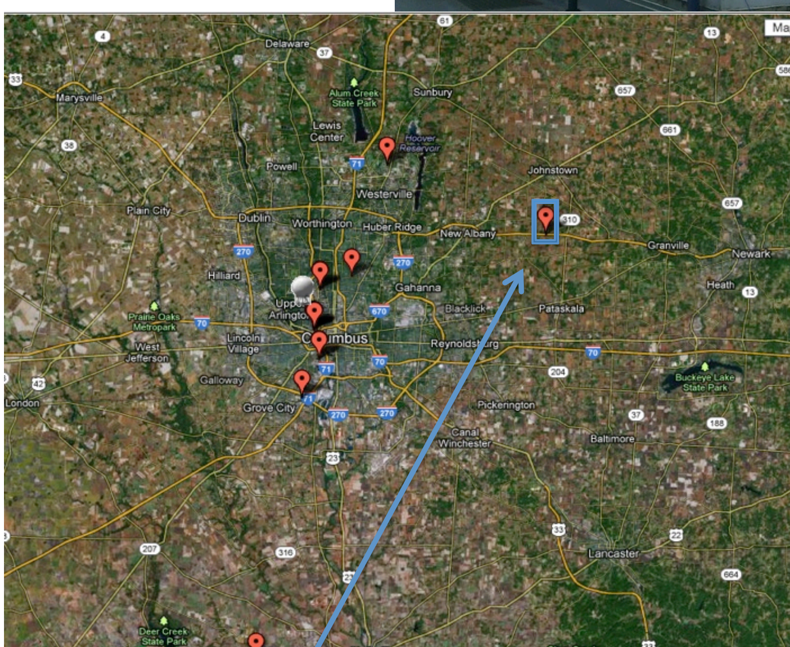


Passive Radar Test-bed

Antenna directed at transmitter of opportunity

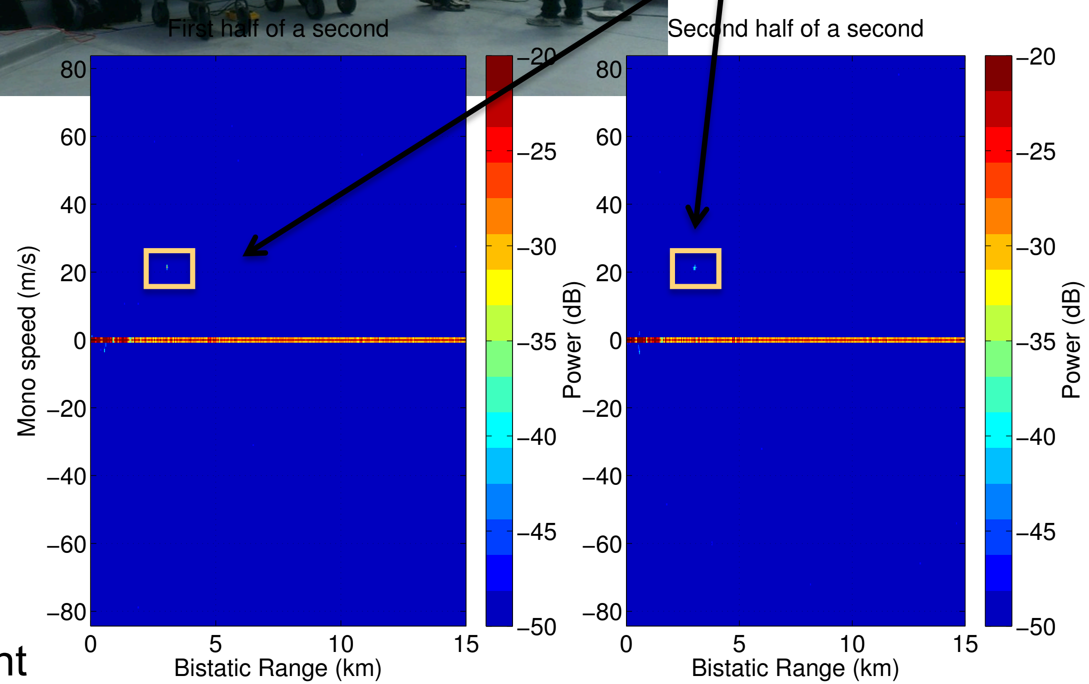
Antenna for observing aircraft

DTV transmitters near Columbus



600 MHz Transmitter used in experiment

Detecting aircraft



Spectrum Sharing

- Wireless spectrum is a scarce resource, but in practice much of it is under-used by current owners

- A “secondary market for spectrum” initiative was first introduce by the Federal Communications Commission in 2000 and further refined and expanded over the following years
  - FCC defined and encouraged the practice of “Dynamic Spectrum Leasing”
  - FCC also made it much easier for spectrum holders to effectively break up a spectrum license into smaller parts

- This means that spectrum can be offered to secondary users for any length of time, time of day, size of coverage area, and frequency or number of channels up to the full capacity of the original license.

- While all these incentives and capabilities have been in place since 2005, very little advantage has been taken of these new leasing and disaggregation rules. A number of reasons:
  - Many license holder worry about “ losing their spectrum”
  - It is difficult for potential buyers to form expectations about the values

Challenges

- Dynamic allocation for dynamic access to freed spectrum
  - Ideally, dynamic allocation mechanisms should be made available
  - As the first step, we consider a “one-shot” auction for the dynamic access of freed spectrum
- Externalities created by sharing
  - The value depends on the way the spectrum is shared with others. The monotonicity of bidding is likely to be violated.
  - Kash, Murty, and Parkes propose SATYA, a strategy-proof and scalable spectrum auction algorithm
  - But the “incentive compatibility” issue is not completely solved in the multi-dimensional bidding environment
- Potential “competition” among commercial and public-good users
  - Public-good users do not “bid” like an industry player …
  - Government should reserve certain spectrum for public use before putting the rest for auction

Substitutes and Complements

- An example with two spectrum licenses, A and B:

	A	B	AB
1	10	10	10
2	10	10	30

Bidder 1's valuation exhibits substitutes, and bidder 2's valuation exhibits complements.

- When different pieces of spectrum can be regarded as substitutes, the simultaneous ascending auction originally proposed by McAfee, Milgrom, and Wilson works well when bidders bid "straightforwardly."

- However, when different pieces of spectrum exhibit complements, there may not exist any price to clear the market. The problem with complements can be partially handled by a combinatorial clock auction proposed by Cramton.

Conclusions

- Spectrum sharing with radiometric sensors is feasible. Impact on the sensing capability should be assessed on a case by case basis.
- Passive radar can provide full US civilian airspace coverage. Exact performance under all conditions needs quantifying.
- The non-standard nature of the spectrum to be freed is not well matched in existing spectrum valuation models
- The state of the art in this new market design suggests a fundamental tradeoff between product design and auction design
  - When the available spectrum is well organized, the auction design and implementation may be greatly simplified
  - A carefully designed auction may help industry participants to form available spectrum